CLAIMS

What is claimed is:

1. A code division, multiple access (CDMA) receiver, comprising a receiver input for coupling to signal outputs of N_{rx} receive antennas, the signal outputs being sampled at N_s samples per symbol or chip, a matched filter, and a whitening filter for coupling the receiver input to an input of the matched filter, said whitening filter comprising N_sN_{rx} parallel whitening filters $\mathbf{w}_{j,k}$, individual whitening filters $\mathbf{w}_{j,k}$ receiving, during each symbol interval I, N_sN_{rx} new signal samples via a signal connection matrix such that a first individual whitening filter receives one of the new samples, a second individual whitening filter receives the same new sample as the first individual whitening filter, and one additional new sample, and such that an nth individual whitening filter receives the same n-1 new samples as the first n-1 individual whitening filters, plus one additional new sample, said whitening filter comprising N_{rx} outputs for outputting filtered signal samples such that a filtered signal sample appearing in the N_{rx} outputs does not correlate with any other filtered signal sample appearing in N_{rx} outputs.

2. A CDMA receiver as in claim 1, further comprising a delay line comprised of a plurality of serially coupled delay line elements each having a delay of one symbol interval, said delay line having an input coupled to an output of said signal connection matrix and providing the N_sN_{rx} parallel whitening filters $\mathbf{w}_{j,k}$ with delayed versions of said signal samples.

3. A CDMA receiver as in claim 2, where for a symbol interval i and where N_sN_{rx} =4, signal vectors output from the delay line elements are defined as:

$$\mathbf{r}(i-1)=\begin{pmatrix} r_{1,1}(i-1) \\ r_{1,2}(i-1) \\ r_{2,1}(i-1) \\ r_{2,2}(i-1) \end{pmatrix},$$

where in the term $r_{n,m}(i)$ the symbols n and m denote an antenna and a symbol sample index, respectively, where an the input signal vector for an arbitrary one of the individual whitening filters $\mathbf{w}_{n,m}$ is denoted by $\mathbf{r}_{n,m}$, the signal connection matrix results in input signal vectors:

$$\mathbf{r}_{1,1}(i)=\begin{pmatrix}\vdots\\ \mathbf{r}(i-2)\\ \mathbf{r}(i-1)\\ r_{1,1}(i)\end{pmatrix}\;;\mathbf{r}_{1,2}(i)=\begin{pmatrix}\vdots\\ \mathbf{r}(i-2)\\ \mathbf{r}(i-1)\\ r_{1,1}(i)\\ r_{1,2}(i)\end{pmatrix}\;;\mathbf{r}_{2,1}(i)=\begin{pmatrix}\vdots\\ \mathbf{r}(i-2)\\ \mathbf{r}(i-1)\\ r_{1,1}(i)\\ r_{1,2}(i)\\ r_{2,1}(i)\end{pmatrix}\;;\mathbf{r}_{2,2}(i)=\begin{pmatrix}\vdots\\ \mathbf{r}(i-2)\\ \mathbf{r}(i-1)\\ \mathbf{r}(i)\end{pmatrix}$$

at the inputs to the individual whitening filters $\mathbf{w}_{n,m}$.

4. A CDMA receiver as in claim 3, where in a direct form solution, taking one of the signal vectors the signal model is expressed as

$$\mathbf{r}_{n,m}(i)=\mathbf{Gb}+\mathbf{n}=\begin{pmatrix}\mathbf{H}\\ \mathbf{h}^T\end{pmatrix}\mathbf{b}+\mathbf{n}\,,$$

where $(\cdot)^T$ denotes transposition, $\mathbf{G}$ is a channel matrix, possibly including the effect of transmitter and receiver filters, $\mathbf{b}$ is a symbol vector and $\mathbf{n}$ a noise vector, and vector $\mathbf{h}^T$ is the bottom row of $\mathbf{G}$, the corresponding individual whitening filter $\mathbf{w}_{n,m}$ output is

$$g_{n,m}(i)=\mathbf{w}_{n,m}^H(i)\mathbf{r}_{n,m}(i)\,,$$

where $(\cdot)^H$ denotes conjugate transposition.

5. A CDMA receiver as in claim 4, where an individual whitening filter $\mathbf{w}_{n,m}$ is obtained by using linear minimum mean-square error (LMMSE) criterion as

$$\mathbf{w}_{n,m}(i)=\begin{pmatrix}-\alpha\mathbf{C}_{n,m}^{-1}\mathbf{Hh}^*\\ 1\end{pmatrix}=\begin{pmatrix}-\mathbf{u}_{n,m}\\ 1\end{pmatrix},$$

in which $(\cdot)^{-1}$ denotes matrix inversion and $(\cdot)^*$ complex conjugation, where symbol α is a real scaling factor, and the covariance matrix of $\mathbf{r}_{n,m}(i)$ is

$$\mathbf{C}_{n,m} = \text{Expectation}\left\{\tilde{\mathbf{r}}_{n,m}(i)\tilde{\mathbf{r}}_{n,m}^H(i)\right\},$$

where the tilde above vector $\mathbf{r}_{n,m}(i)$ denotes an operation where the bottom element of the original vector is excluded.

6. A CDMA receiver as in claim 5, where the unfixed part $\mathbf{u}_{n,m}$ of the whitening filter is made adaptive in accordance with:

$$\mathbf{u}_{n,m} \leftarrow \mathbf{u}_{n,m} + \mu\left\{g_{n,m}^*(i)\tilde{\mathbf{r}}_{n,m}(i)\right\},$$

where parameter μ is a step size factor.

7. A CDMA receiver as in claim 1, where said whitening filter is implemented using serially coupled lattice stages that form a lattice filter.

8. A method for operating a code division, multiple access (CDMA) receiver, comprising:

coupling a receiver input to signal outputs of N_{rx} receive antennas, the signal outputs being sampled at N_s samples per symbol,

whitening the signal outputs; and

filtering the whitened signal outputs with a matched filter, where

whitening uses a whitening filter comprising N_sN_{rx} parallel whitening filters $\mathbf{w}_{j,k}$, individual whitening filters $\mathbf{w}_{j,k}$ receiving during each symbol interval i, N_sN_{rx} new signal samples via a signal connection matrix such that a first individual whitening filter receives only one of the new samples, a second individual whitening filter receives the

same sample as the first individual whitening filter, and one additional sample, and such that an nth individual whitening filter receives the same n-1 samples as the first n-1 individual whitening filters, plus one of the remaining samples, and outputting from said whitening filter, over N_{rx} outputs, filtered signal samples such that a filtered signal sample appearing in the N_{rx} outputs does not correlate with any other filtered signal sample appearing in N_{rx} outputs.

9. A method as in claim 8, further comprising operating a delay line comprised of a plurality of serially coupled delay line elements each having a delay of one symbol interval, said delay line having an input coupled to an output of said signal connection matrix and providing the N_sN_{rx} parallel whitening filters $\mathbf{w}_{j,k}$ with delayed versions of said signal samples.

10. A method as in claim 9, where for a symbol interval i and where $N_sN_{rx}=4$, signal vectors output from the delay line elements are defined as:

$$\mathbf{r}(i-1)=\begin{pmatrix} r_{1,1}(i-1) \\ r_{1,2}(i-1) \\ r_{2,1}(i-1) \\ r_{2,2}(i-1) \end{pmatrix},$$

where in the term $r_{n,m}(i)$ the symbols n and m denote an antenna and a symbol sample index, respectively, where an the input signal vector for an arbitrary one of the individual whitening filters $\mathbf{w}_{n,m}$ is denoted by $\mathbf{r}_{n,m}$, the signal connection matrix results in input signal vectors:

$$\mathbf{r}_{1,1}(i)=\begin{pmatrix} \vdots \\ \mathbf{r}(i-2) \\ \mathbf{r}(i-1) \\ r_{1,1}(i) \end{pmatrix} ;\mathbf{r}_{1,2}(i)=\begin{pmatrix} \vdots \\ \mathbf{r}(i-2) \\ \mathbf{r}(i-1) \\ r_{1,1}(i) \\ r_{1,2}(i) \end{pmatrix} ;\mathbf{r}_{2,1}(i)=\begin{pmatrix} \vdots \\ \mathbf{r}(i-2) \\ \mathbf{r}(i-1) \\ r_{1,1}(i) \\ r_{1,2}(i) \\ r_{2,1}(i) \end{pmatrix} ;\mathbf{r}_{2,2}(i)=\begin{pmatrix} \vdots \\ \mathbf{r}(i-2) \\ \mathbf{r}(i-1) \\ \mathbf{r}(i) \end{pmatrix}$$

at the inputs to the individual whitening filters $\mathbf{w}_{n,m}$.

11. A method as in claim 10, where in a direct form solution, taking one of the signal vectors the signal model is expressed as

$$\mathbf{r}_{n,m}(i) = \mathbf{G}\mathbf{b} + \mathbf{n} = \begin{pmatrix} \mathbf{H} \\ \mathbf{h}^T \end{pmatrix} \mathbf{b} + \mathbf{n},$$

where $(\cdot)^T$ denotes transposition, $\mathbf{G}$ is a channel matrix, possibly including the effect of transmitter and receiver filters, $\mathbf{b}$ is a symbol vector and $\mathbf{n}$ a noise vector, and vector $\mathbf{h}^T$ is the bottom row of $\mathbf{G}$, the corresponding individual whitening filter $\mathbf{w}_{n,m}$ output is

$$g_{n,m}(i) = \mathbf{w}_{n,m}^H(i)\mathbf{r}_{n,m}(i),$$

where $(\cdot)^H$ denotes conjugate transposition.

12. A method as in claim 11, where an individual whitening filter $\mathbf{w}_{n,m}$ is obtained by using linear minimum mean-square error (LMMSE) criterion as

$$\mathbf{w}_{n,m}(i) = \begin{pmatrix} -\alpha\mathbf{C}_{n,m}^{-1}\mathbf{H}\mathbf{h}^* \\ 1 \end{pmatrix} = \begin{pmatrix} -\mathbf{u}_{n,m} \\ 1 \end{pmatrix},$$

in which $(\cdot)^{-1}$ denotes matrix inversion and $(\cdot)^*$ complex conjugation, where symbol α is a real scaling factor, and the covariance matrix of $\mathbf{r}_{n,m}(i)$ is

$$\mathbf{C}_{n,m} = \text{Expectation}\{\tilde{\mathbf{r}}_{n,m}(i)\tilde{\mathbf{r}}_{n,m}^H(i)\},$$

where the tilde above vector $\mathbf{r}_{n,m}(i)$ denotes an operation where the bottom element of the original vector is excluded.

13. A method as in claim 12, where the unfixed part $\mathbf{u}_{n,m}$ of the whitening filter is made adaptive in accordance with:

$$\mathbf{u}_{n,m} \leftarrow \mathbf{u}_{n,m} + \mu\{g^{*}_{n,m}(i)\tilde{\mathbf{r}}_{n,m}(i)\},$$

where parameter μ is a step size factor.

14. A method as in claim 7, where said whitening filter is implemented using serially coupled lattice stages that form a lattice filter.

15 A code division, multiple access (CDMA) mobile station, said mobile station comprising a receiver coupled to N_{rx} receive antennas and further comprising baseband circuitry for sampling signal outputs of said N_{rx} receive antennas at N_s samples per symbol or chip, said baseband circuitry further comprising a multi-antenna RAKE receiver and a whitening filter for coupling the sampled signals to inputs of said multi-antenna RAKE receiver, said whitening filter comprising N_sN_{rx} parallel whitening filters $\mathbf{w}_{j,k}$, individual whitening filters $\mathbf{w}_{j,k}$ receiving, during each symbol interval I, N_sN_{rx} new signal samples via a signal connection matrix such that a first individual whitening filter receives one of the new samples, a second individual whitening filter receives the same new sample as the first individual whitening filter, and one additional new sample, and such that an nth individual whitening filter receives the same n-1 new samples as the first n-1 individual whitening filters, plus one additional new sample, further comprising a delay line comprised of a plurality of serially coupled delay line elements each having a delay of one symbol interval, said delay line having an input coupled to an output of said signal connection matrix and providing the N_sN_{rx} parallel whitening filters $\mathbf{w}_{j,k}$ with delayed versions of said signal samples, said whitening filter comprising N_{rx} outputs for outputting whitened filtered signal samples to said multi-antenna RAKE receiver.

16. A CDMA mobile station as in claim 15, where said whitening filter and said multi-antenna RAKE receiver together comprise a linear (minimum mean-square error) channel equalizer.

17. A CDMA mobile station as in claim 15, where said whitening filter and said multi-antenna RAKE receiver together comprise a multi-antenna space-time equalizer that optimally performs beam-forming while suppressing inter-cell interference.

18. A CDMA mobile station as in claim 15, where said same whitening filter is used for receiving transmissions from a plurality of base stations during a soft handoff procedure.